California Division of Mines and Geology
Fault Evaluation Report FER-181
Pinto Mountain, Mesquite Lake, Copper Mountain,
and related faults,
Southern San Bernardino County, California

by

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INTRODUCTION

Potentially active faults in southern San Bernardino County that are evaluated in this Fault Evaluation Report (FER) include the Pinto Mountain, Mesquite Lake, Copper Mountain, and related faults (figure 1). The Yucca Valley - Twentynine Palms study area is located in parts of the Queen Mountain, Twentynine Palms, Sunfair, Joshua Tree North, Yucca Valley North, and Yucca Valley South 7 1/2' quadrangles and the Valley Mountain 15' quadrangle (figure 1). These faults are evaluated as part of a statewide effort to evaluate faults for recency of activity. Those faults determined to be sufficiently active and well-defined are zoned by the State Geologist as directed by the Alquist-Priolo Special Studies Zones Act (Hart, 1985).

Traces of the western segment of the Pinto Mountain fault zone and Morongo Valley fault were zoned for special studies in 1974 west of the Yucca Valley - Twentynine Palms study area in the SE 1/4 and SW 1/4 of the Morongo Valley 15' quadrangle (figure 1). These two quadrangles will not be evaluated in this FER. Re-evaluation of these quadrangles should be accomplished if time and scheduling permit because zoning for special studies in 1974 was based on the criterion of Quaternary-active faulting. Some faults in these quadrangles may not meet the current criteria for zoning.

SUMMARY OF AVAILABLE DATA

The Yucca Valley - Twentynine Palms study area is transitional between the Mojave Desert and Transverse Ranges geomorphic provinces. The Mojave Desert geomorphic province is characterized by generally northwest-trending, right-lateral strike-slip faults. The Pinto Mountain fault zone, located in both the Transverse Ranges and Mojave Desert geomorphic provinces, is an east-west-trending, left-lateral strike-slip fault more characteristic of structures within the Transverse Ranges (figure 1). Both the northwest-trending and east-trending faults are the result of compressional tectonics along the San Andreas fault system. The interaction between these two tectonically active systems has resulted in a structurally complex area.

Topography in the study area ranges from relatively flat playa surfaces and alluvial floodplains to hills of moderately rugged relief. Rainfall is very sparse in the area, annually averaging about 10cm. However, precipitation is seasonal and usually falls in a few intense storms in the late summer. Thus, land surfaces are subject to occasionally intense, episodic periods of erosion or gradation. Development in the study area is moderately heavy in the Yucca Valley, Joshua Tree, and Twentynine Palms areas.

Rock types in the study area include pre-Cambrian (?) metamorphic rocks, Mesozoic plutonic rocks (granitic), Plio-Pleistocene terrestrial deposits, Pleistocene and Holocene alluvium, eolian deposits, and playa deposits (Bader and Moyle, 1960; Bishop, 1963; Rogers, 1967; Dibblee, 1967, 1968a; Bacheller, 1978; Grimes, 1981; Wahler Associates, 1984). Late Pleistocene and Holocene alluvial deposits are extensive throughout most of the study area and, locally, late Holocene alluvium conceals significant segments of the Pinto Mountain fault.

PINTO MOUNTAIN FAULT

The Pinto Mountain fault is a major, 80-km-long, left-lateral strike-slip fault that forms the boundary between the Mojave Desert and Transverse Ranges geomorphic provinces (figure 1). Segments of the Pinto Mountain and Morongo Valley faults west of the FER study area were zoned for special studies in 1974 and will not be evaluated in this FER (CDMG, 1974a, 1974b).

Cumulative left-lateral, strike-slip displacement along the Pinto Mountain fault may total 16 km, according to Dibblee (1975). Dibblee (1968b, 1975) stated that the magnitude of left-lateral displacement diminishes westward from the maximum of 16 km near the central part of the fault zone to up-on-the-north vertical displacement in the western part of the study area. Bacheller (1978) stated that up to 19 km of left-lateral displacement has occurred in Mesozoic bedrock along the Pinto Mountain fault in the Twentynine Palms area. Quaternary slip-rates along the Pinto Mountain fault are estimated to be between 1 mm/yr and 5 mm/yr. Dibblee (1968b) mapped a Quaternary gravel unit as offset approximately 9.6 km along the Pinto Mountain fault, suggesting a slip-rate of about 5.3 mm/yr (Bird and Rosenstock, 1984).

The Pinto Mountain fault was first mapped by Hill (1928), based on an exposure of the fault along the northern side of the Pinto Mountains and Little San Bernardino Mountains. Mapping that will be evaluated in this FER includes Bader and Moyle (1960) and Dibblee (1967, 1968a) (figures 2a-2d). In addition, Grimes (1981) mapped segments of the Pinto Mountain fault zone in the extreme western part of the study area (figure 2d) and Bacheller (1978) mapped segments of the Pinto Mountain fault zone in the eastern part of the study area (figure 2a). None of the previously cited maps specifically addressed recently active faulting and none are annotated with evidence for fault recency. The Pinto Mountain fault will be discussed from east to west.

Twentynine Palms and Valley Mountain Quadrangles

Segments of the Pinto Mountain fault zone in the Twentynine Palms and Valley Mountain quadrangles have been mapped by Bader and Moyle (1960), Dibblee (1968a), and Bacheller (1978) (figure 2a). The Pinto Mountain fault zone is complex east of Twentynine Palms, due principally to the interaction with the Mesquite Lake fault, a right-lateral, strike-slip fault (figures 1, 2a).

Faults mapped by Bacheller (1978) in the Valley Mountain quadrangle form a broad, distributive zone of both normal and strike-slip faults (figure 2a). Late Pleistocene and Holocene alluvium are offset along segments of these faults (figure 2a). The Pinto Mountain fault zone consists of three branches in the Twentynine Palms quadrangle in the area east of Donnell Hill (locality 1, figure 2a). Bacheller (1978) mapped the northern, central, and southern branches of the Pinto Mountain fault; Bader and Moyle (1960) mapped the northern and central segments, and Dibblee (1968a) mapped the central and southern segments (figure 2a). The northern branch offsets late (?) Pleistocene alluvium at locality 2 (figure 2a), but Holocene alluvium generally is not offset except where mapped by Bader and Moyle at locality 4 (figure 2a). The southern branch fault, which offsets late Pleistocene alluvium, is a zone of generally discontinuous normal faults (e.g., graben at locality 5, figure 2a). Holocene alluvium is not offset (Dibblee, 1968a; Bacheller, 1978) (figure 2a). There is considerable disagreement as to location and continuity (inferred, partly concealed) of the north and south branches.

The central branch fault, probably the principal active trace of the Pinto Mountain fault, offsets Holocene alluvium at the Oasis of Mara (locality 3, figure 2a) (Dibblee, 1968a; Bacheller, 1978). There is generally good agreement with respect to the location of the fault at locality 3, although Bader and Moyle mapped the fault as concealed by Holocene alluvium (figure 2a). The central branch fault forms a significant groundwater barrier at locality 3 where the groundwater level is very near the surface south of the fault and approximately 100 feet below the surface on the north side of the fault (Bader and Moyle, 1960)(figure 2a).

West of Donnell Hill, a pressure ridge (?) underlain by early to mid-Pleistocene alluvium (Campbell Hill Formation of Bacheller, 1978), agreement with respect to the location of the Pinto Mountain fault is poor between Bader and Moyle (1960), Dibblee (1968a), and Bacheller (1978) (figure 2a). Reeder and Rasmussen (1983) interpreted air photos in the vicinity of locality 39 (figure 2a) and reported a possible scarp in latest Pleistocene to Holocene alluvium. James (1986) excavated 1230 meters of trenches at this site and reported evidence of Holocene displacement (locality 39, figure 2a). The fault interpreted by Reed and Rasmussen was verified, and a broad, distributive zone of generally minor, down-to-the-south normal faults was reported. Alluvium identified as Holocene is displaced up to 61 cm in an apparent vertical sense along generally east-trending faults; the magnitude of strike-slip displacement is not known. This zone of minor, distributive faulting is located between fault traces mapped by Bader and Moyle, Dibblee, and Bacheller (figure 2a). The fault mapped by Bader and Moyle locally was verified in trench T-7, but evidence for or against recent faulting was not present.

Sunfair Quadrangle

A single, east-west-trending fault was mapped by Bader and Moyle (1960) and Dibblee (1968a) in the Sunfair quadrangle (figure 2b). Relatively good agreement with respect to fault location exists between Bader and Moyle and Dibblee near locality 6 (figure 2b). Pleistocene and Holocene alluvium are offset along the Pinto Mountain fault at locality 6. East and west of this 5-km-long segment, the Pinto Mountain fault is concealed by late(?) Holocene alluvium (figure 2b).

Joshua Tree North Quadrangle

There is significant disagreement with respect to the location of traces of the Pinto Mountain fault mapped by Bader and Moyle (1960) and Dibblee (1967) in the Joshua Tree North quadrangle (figure 2c). Pleistocene and, locally, Holocene alluvium are offset along traces of the Pinto Mountain fault (figure 2c).

A site investigation by Rasmussen (1977) exposed evidence of latest Pleistocene and Holocene offset near the fault mapped by Bader and Moyle (1960) (locality 7, figure 2c). A fault zone at least 13 meters wide offsets latest Pleistocene alluvium against Holocene alluvium (figure 4). Fault planes strike from N75°W to N85°E and have vertical to steeply north dips (figure 4). A thin soil overlies the fault zone, but it was not specified whether this was an A soil horizon, or perhaps a veneer of late Holocene eolian sand. Rasmussen (1977) concluded that the fault was Holocene active.

North of the Rasmussen (1977) site, along the general trend of Dibblee's (1967) fault, notches, aligned gullies, and scarps in Pleistocene alluvium were reported by Spittler and Rasmussen (1980) (locality 8, figure 2c). Shear planes in older alluvium were exposed in a road cut along Sunny Vista Road, but it was not determined what magnitude of offset, if any, had occurred along these shears. No trenching was performed at this site. It was suggested by Spittler and Rasmussen that the geomorphic features could be related to erosion rather than faulting.

Yucca Valley North and Yucca Valley South Quadrangles

The Pinto Mountain fault zone in the Yucca Valley North and South quadrangles forms a broad zone of faulting mapped by Bader and Moyle (1960), Dibblee (1967), and Grimes (1981) (figure 2d). Generally, there is little to no agreement between these workers with respect to the location of faults. Faults mapped by Bader and Moyle, which are located south of the faults mapped by Dibblee (1967), offset Pleistocene alluvium and, possibly, Holocene alluvium (e.g., locality 9, figure 2d). Dibblee's fault traces are generally located along the base of a south-facing escarpment that juxtaposes granitic bedrock against Holocene alluvium (figure 2d). Dibblee (1967, 1968b) postulated that displacement along the Pinto Mountain fault in this vicinity was predominantly dip slip (up-on-the-north). Dibblee (1967) also mapped a northern branch of the Pinto Mountain fault in the Water Canyon area (locality 10, figure 2d). Grimes (1981) also mapped a fault in the Water Canyon area, but late Pleistocene deposits are not offset along this fault (locality 10, figure 2d).

A southern branch of the Pinto Mountain fault zone, named the Morongo Valley fault, was mapped by Bader and Moyle (1960), Dibblee (1967), and Grimes (1981) (figure 2d). Dibblee mapped Pleistocene deposits juxtaposed against Holocene alluvium, while Grimes mapped the fault as concealed by Holocene alluvium (locality 12, figure 2d). Bader and Moyle (1960) mapped the Morongo Valley fault farther to the south and mapped late Pleistocene alluvium and, possibly, Holocene alluvium offset along the fault (figure 2d).

A site investigation by Bush and Rasmussen (1979) excavated trenches along a concealed fault mapped by Dibblee (1967) (locality 13, figure 2d). The trenches were excavated in Holocene alluvium and several fractures were reported in a 70-meter zone (figure 5). Bedding in the alluvium was not discernably offset, but the fractures had orientations consistent with the general trend of the Pinto Mountain fault. The consultant concluded that the fractures were not formed by fault rupture but were probably formed by shaking from nearby earthquakes, possibly along the Pinto Mountain fault. However, it may be difficult to dismiss faulting because: (1) the orientation of the fractures are consistent with the trend of the Pinto Mountain fault zone, and (2) the alluvium in which the fractures were reported seems to be very young (mid- to late-Holocene according to consultants) and may be comparable to the young alluvium concealing large segments of the Pinto Mountain fault to the east (figures 2b, 2c).

MESQUITE LAKE FAULT

The Mesquite Lake fault is a northwest-trending, right-lateral strike-slip fault (Dibblee, 1968a; Bacheller, 1978; Wahler Associates, 1984) (figures 1, 2a). The fault zone is about 18 km long within the Yucca Valley - Twentynine Palms study area. The Mesquite Lake fault is located within a structural basin bounded on the east by the West Bullion Mountain fault (figures 1, 2a). The deepest part of the structural basin lies west of the Mesquite Lake fault, suggesting a slight down-to-the-west component of vertical displacement, based on gravity surveys by Wahler Associates (1984).

The Mesquite Lake fault forms a significant groundwater barrier: the difference in groundwater levels is approximately 200 feet across the fault, down on the east (Bader and Moyle, 1960; figure 2a). The magnitude of right-lateral strike-slip displacement is not known along the Mesquite Lake fault. The Calico fault zone, of which the Mesquite Lake fault is considered to be a southern segment, is estimated to have between 10 and 20 km of right-lateral displacement by Garfunkel (1974). Dokka (1983) disputed this and estimated that approximately 8.2+ km of right slip has occurred along the Calico fault zone. Clark and others (1984), using the data from Dokka (1983), estimated a late-Quaternary slip-rate from 0.4 mm/yr to 5 mm/yr along the Calico fault zone. Wahler Associates (1984) speculated that about 12 km of right slip may have occurred along the Mesquite Lake fault, based on the probable offset of Pleistocene sediments between Ocotillo Heights (locality 14) and Campbell Hill (locality 15) (figure 2a). This doesn't seem reasonable because: (1) it is questionable that Wahler Associates can adequately constrain offset of the Campbell Hill Formation (?) of Bacheller (1978) along the Mesquite Lake fault--this formation occurs extensively along both sides of the fault, and it is doubtful that reliable "piercing points" could have been identified; (2) if the Campbell Hill Formation (?) were offset about 12 km along the Mesquite Lake fault, a Quaternary slip-rate of about 17 mm/yr would be indicated (based on 12 km of offset during the last 0.7 my).

The Mesquite Lake fault in the study area has been mapped by Bader and Moyle (1960), Dibblee (1968a), Bacheller (1978), Morton and others (1980), and Wahler Associates (1984) (figure 2a). Generally, there is good agreement regarding the location of the principal trace of the Mesquite Lake fault, although differences in detail exist (figure 2a). Specifically, differences exist along the northern part of the fault zone near locality 14 and south and southeast of Campbell Hill (locality 15) where the Mesquite Lake fault merges with the Pinto Mountain fault zone (figure 2a).

Holocene alluvium, playa deposits, and eolian deposits are offset along the Mesquite Lake fault (Bader and Moyle, 1960; Dibblee, 1968a; Bacheller, 1978; Wahler Associates, 1984) (figure 2a). South of Campbell Hill, Bacheller (1978) mapped a west branch of the Mesquite Lake fault (figure 2a). This west branch fault consists of numerous sub-parallel faults that offset Pleistocene Campbell Hill and Twentynine Palms Formations, but not Holocene alluvium (figure 2a). Morton and others (1980) mapped recently active traces of the Mesquite Lake fault (figure 2a). Geomorphic features indicating recent faulting were interpreted from aerial photographs and fault traces were annotated (figure 2a). However, fault traces were not field-checked.

Wahler Associates (1984) excavated a number of trenches across the Mesquite Lake fault (figure 2a). Faults with average strikes of N25^{o}W and vertical to near-vertical dips were reported in most of the trenches. In trench T-4b, an offset carbonaceous silt deposit yielded radiocarbon dates between 1220 and 1730 ybp (locality 16, figure 2a; figure 6). In addition, sand boils were reported in trenches T-4c and T-5c, and sand-filled fissures associated with faulting were reported in T-5A (figure 2a). Trench T-6 exposed a 20-meter-wide fault zone concealed by about 1.8 meters of late Pleistocene to Holocene alluvium (figure 2a).

The "Airfield fault" was first described by Fife (1978) as a 914-meter-long, north-trending, right-stepping en echelon fault (figure 2a). Fractures were first noticed following a period of unusually heavy precipitation in 1976. These extensional cracks were trenched by Wahler Associates in 1984, and it was reported that bedded deposits were not offset along these fractures either laterally or vertically (figure 2a). However, it was reported that more than one period of extension has occurred along these fractures, based on the observation by Fife (1978) that a small crack had been filled and covered by grading in 1952. Wahler Associates (1984) stated that no evidence of an underlying structure indicative of faulting was observed along the "Airfield fault", based on geophysical surveys (magnetic, gravity, seismic). Both Fife (1978, 1980) and Wahler Associates (1984) concluded that formation of the "Airfield fault" was probably a combination of left-lateral shear and extension in response to movement along the Mesquite Lake fault.

WEST BULLION MOUNTAIN FAULT

The West Bullion Mountain fault is a northwest-trending fault located about 1.8 km east of the Mesquite Lake fault (figure 2a). The magnitude and sense of displacement along the West Bullion Mountain fault are not precisely known. It is primarily vertical (up on the east), with a component of right-lateral strike-slip displacement (Dibblee, 1968a; Bacheller, 1978). Wahler Associates (1984) postulated several hundred to several thousand feet of down-to-the-west bedrock displacement along the West Bullion Mountain fault, based on seismic refraction studies.

The West Bullion Mountain fault has been mapped by Dibblee (1968a), Bacheller (1978), and Wahler Associates (1984) (figure 2a). The entire length of fault in the study area is concealed by late Pleistocene and Holocene alluvium (figure 2a). Trenching by Wahler Associates (1984) comfirmed the location of the West Bullion Mountain fault (locality 17, figures 2a, 7). Late Pleistocene alluvium is offset vertically (down to the west) (figure 7) and Wahler Associates concluded that the fault was potentially active and building setbacks were recommended. Site investigations by Foster (1985) near locality 17 reported that the West Bullion Mountain fault does not offset an overlying, moderately developed argillic B soil horizon thought by R. Shlemon to be between 35,000 and 50,000 years old.

COPPER MOUNTAIN FAULT

The Copper Mountain fault is a 15-km-long, northwest-trending fault mapped by Bader and Moyle (1960), Dibblee (1967, 1968a), and Morton and others (1980) (figures 2b, 2c). The Copper Mountain fault is delineated by a sharp, linear, southwest-facing escarpment in Mesozoic bedrock. The magnitude and sense of displacement along the fault are not well-known. Dibblee (1968a) indicated that the primary sense of displacement is vertical, up-on-the-east (figure 2b). However, a component of right-lateral strike-slip displacement would be expected along the fault because of its northwest orientation.

Both Dibblee (1967, 1968a) and Bader and Moyle (1960) mapped Holocene alluvium juxtaposed against Mesozoic granitic bedrock (figures 2b, 2c). The southeastern segment of the Copper Mountain fault does not offset Pleistocene deposits (figure 2b) and Holocene alluvium is not offset along the fault northwest of Sunfair Road (locality 18, figure 2c). Morton and others (1980) mapped recently active traces of the Copper Mountain fault, based on aerial photographic interpretation (no field-checking) (figures 2b, 2c).

Bull (1978) considered the linearity of the southwestern front of the Copper Mountains to represent a Class I mountain front (tectonically active). At locality 19, an alluvial fan is vertically offset and shears in the alluvium were reported (figure 2b). The reported fan surface morphology and the lack of cambic or argillic soil horizons indicate that the alluvial fan is mid-Holocene in age (Bull, 1978).

NORTHWEST-TRENDING FAULTS NORTH OF PINTO MOUNTAIN FAULT (FAULTS A-I)

Several unnamed northwest-trending faults north of the Pinto Mountain fault and exclusive of the Mesquite Lake and Copper Mountain faults were mapped by Bader and Moyle (1960) (faults A-I) and Dibblee (1967, 1968a) (faults B, C, E, F) (figures 2a-2d). Many differences in detail exist between mapping by Bader and Moyle and Dibblee (figures 2a-2d). The magnitude and sense of displacement along these northwest-trending faults generally are not known. Bacheller (1978) mapped fault A (figure 2a) and indicated that it was primarily characterized by right-lateral strike-slip displacement. Faults B, C, and D have up-on-the-east vertical displacements (figure 2b). All of the faults are reported to offset Pleistocene alluvium and Holocene alluvium locally is juxtaposed against either bedrock or Pleistocene alluvium. A site investigation by Spittler and Rasmussen (1980) found no evidence for faulting in late Pleistocene and Holocene alluvium along fault G, based on aerial photographic interpretation and field mapping (no trenching).

Fault I mapped by Bader and Moyle (1960) is the southern projection of the Johnson Valley fault. North of the study area minor surface fault rupture associated with the March 1979 Homestead Valley earthquake was mapped along short segments of the Johnson Valley fault (Hill and others, 1980). Bader and Moyle mapped late Pleistocene alluvium offset along fault I, but Holocene alluvium is not offset (figure 2d).

INTERPRETATION OF AERIAL PHOTOGRAPHS AND FIELD OBSERVATIONS

Aerial photographic interpretation by this writer of faults in the Yucca Valley - Twentynine Palms study area was accomplished using U.S. Department of Agriculture (AXL, 1952-53, scale 1:20,000) and U.S. Bureau of Land Management (CAHD-77, 1978, scale 1:30,000) air photos.

Approximately 5-1/2 days were spent in the study area in January, February, and March 1986 by this writer. In January 1986, this writer was accompanied in the field by E. Hart and M. Manson. Selected fault segments were verified and subtle features not observable on the aerial photographs were mapped in the field. Results of aerial photographic interpretation and field observations by this writer are summarized on figures 3a-3d.

PINTO MOUNTAIN FAULT

The Pinto Mountain fault zone in the study area generally is well-defined (figures 3a-3d), although significant segments of the fault are concealed by late Holocene alluvium, such as at localities 20 and 21 (figure 3b). The Pinto Mountain fault zone is complex and distributive in the eastern part of the study area near its junction with the active, right-lateral Mesquite Lake fault (figures 2a, 3a). A broad zone of subsidiary, discontinuous, normal faults offset late Pleistocene alluvial fans, but Holocene alluvium is not offset (e.g., localities 5 and 33, figure 3a). The Pinto Mountain fault zone is complex and significantly less well-defined at the western end of the study area in and west of Yucca Valley (figures 2d, 3d), probably because the fault zone apparently steps left (south) into Morongo Valley (Morongo Valley fault) and because active sedimentation occurs within the Yucca Valley area. The Morongo Valley fault is generally not well-defined in detail and is not characterized by geomorphic features indicating Holocene faulting (figure 2d).

The Pinto Mountain fault zone throughout most of the study area is characterized by geomorphic evidence of Holocene left-lateral strike-slip faulting, such as scarps in late Pleistocene and Holocene alluvium, left-laterally deflected drainages, sidehill benches, a linear trough in Holocene alluvium, linear ridges in Pleistocene alluvium, and strong vegetation contrasts in Holocene alluvium (localities 3, 6, 7, 13, 22-25, figures 3a-3d).

Faceted spurs indicate a component of up-to-the-south vertical displacement at locality 23 (figure 3b). Evidence of multiple offsets was observed here where faceted spurs in Pleistocene Campbell Hill Formation merge with a linear scarp that extends into Holocene terrace deposits (locality 23, figure 3b; photo 1). A fault plane coincident with the faceted spurs and scarp trends N85^{o}E and dips 70^{o}N - striations along the fault plane plunge 15^{o}-20^{o}W, indicating an up-on-the-south component of vertical displacement (locality 23, figure 3b; photos 2 and 3).

The Pinto Mountain fault zone at the western end of the study area is complex and is characterized by a significant component of vertical displacement. Recent activity seems to step left from the Pinto Mountain fault to the Morongo Valley fault as indicated by the large, closed basin bounded on the north and west by generally south-facing scarps in Pleistocene alluvium (locality 30, figure 3d). Holocene alluvium is not offset, but it is probably late Holocene in age.

Traces of the Pinto Mountain fault mapped by Bader and Moyle (1960) were generally verified throughout most of the study area, although significant differences in detail exist, specifically in the Yucca Valley area (figures 2a-2d, 3a-3d). Traces of the Pinto Mountain fault mapped by Dibblee (1967, 1968a) generally were not verified as Holocene active faults except in the vicinity of localities 3, 6, and 13 (figures 2a-2d, 3a-3d). Principal active traces of the Pinto Mountain fault mapped by Bacheller (1978) were generally verified by this writer (figures 2a, 3a).

West of Donnell Hill, a pressure ridge(?) in Pleistocene Campbell Hill Formation, the Pinto Mountain fault is less well-defined and traces mapped by Bacheller were not verified except locally at locality 26 (figure 2a). The fault mapped by Reeder and Rasmussen (1983) was verified by this writer just west of the James (1986) site (locality 39, figure 3a). Although James (1986) demonstrated that Holocene-active faults exist in a distributive zone, geomorphic evidence of recent faulting was not observed by this writer at and east of the site (figure 3a). The predominantly normal sense of displacement reported by James (1986) at this location and the pattern of recent faulting between localities 26, 39, and Donnell Hill indicate a complex, left-stepping configuration of recently active strands of the Pinto Mountain fault zone just west of Twentynine Palms.

Faults mapped by Grimes (1981) in the Yucca Valley area generally correspond with traces mapped by Dibblee (1967). A short, east-trending fault mapped by Grimes that offsets late Pleistocene alluvium is poorly defined and was not verified by this writer (locality 11, figure 2d).

The deposits forming the faulted terrace near the Rasmussen (1977) site have variously been mapped as Plio-Pleistocene continental deposits (Bader and Moyle, 1960) and Pleistocene to late Pleistocene older alluvium by Dibblee (1967) (locality 7, figures 2c, 3c). However, a road cut exposure and a soil pit within these terrace deposits reveal a very weak soil development, indicating a latest Pleistocene (locality 28) and Holocene (locality 27) age for the terrace deposits (figure 3c).

No evidence of fault creep was observed along selected traces of the Pinto Mountain fault (figures 3a-3d).

MESQUITE LAKE FAULT

The Mesquite Lake fault is a generally well-defined, northwest-trending fault that forms a linear boundary between latest Pleistocene to Holocene eolian sand deposits on the west and Holocene alluvium and playa deposits on the east (figures 2a, 3a). Geomorphic evidence of Holocene right-lateral strike-slip faulting includes scarps and a linear trough in late Pleistocene and Holocene deposits, closed depressions, right-laterally deflected drainages, and sharp tonal lineaments and vegetation contrasts in Holocene alluvium (e.g., localities 29-32, figure 3a).

Mapping by Bader and Moyle (1960), Dibblee (1968a), Bacheller (1978), Morton and others (1980), and Wahler Associates (1984) generally was verified by this writer, although differences in detail exist, especially along the northwestern and southeastern ends of the fault (figures 2a, 3a). Traces of the Mesquite Lake fault mapped by Wahler Associates (1984) were verified at the extreme northern end of the study area, although immediately to the south the Wahler Associates fault should be mapped as concealed by Holocene alluvium (figures 2a, 3a). The western branch of the Mesquite Lake fault mapped by Bacheller (1978) is not well defined and was not verified by this writer (figures 2a, 3a). Short, discontinuous, linear ridges and escarpments in Pleistocene Twentynine Palms Formation could be formed by discontinuous faulting, or conceivably could be formed by differential erosion (locality 33, figure 3a).

The "Airfield fault" of Fife (1978) is delineated by sharp tonal lineaments in Holocene alluvium visible on 1978 BLM air photos. However, these features were not observed on 1952 U.S.D.A. air photos, and associated geomorphic features are lacking.

WEST BULLION MOUNTAIN FAULT

The West Bullion Mountain fault, mapped as concealed by Dibblee (1968a), Bacheller (1978), and Wahler Associates (1984), is not a well-defined surface feature and is not delineated by geomorphic features indicating recent normal or strike-slip faulting (figure 2a).

COPPER MOUNTAIN FAULT

The northwest-trending Copper Mountain fault is delineated by a well-defined, southwest-facing escarpment in Mesozoic bedrock (figure 3b). Geomorphic evidence of predominantly normal faulting includes vertically offset Holocene alluvial fans and a vertically offset drainage (localities 19 and 34, figure 3a). South of sec. 2 T1N, R7E, specific geomorphic features indicating recent faulting were not observed by this writer (figures 2b, 3b). Northwest of Sunfair Road, a dissected, west-facing scarp in Pleistocene alluvium indicates the location of the Copper Mountain fault, but specific well-defined geomorphic features indicating Holocene faulting were not observed (figure 3b, 3c).

The small-scale geomorphic features along the Copper Mountain fault generally are very subtle, based on air photo interpretation and field checking by this writer (figures 3b, 3c). However, there are stream-cut exposures that clearly show that alluvium of probable Holocene age is offset (e.g., locality 19, figure 3b, photos 4, 5).

NORTHWEST-TRENDING FAULTS (FAULTS A-I)

Generally, these northwest-trending faults mapped by Bader and Moyle (1960) and Dibblee (1967, 1968a) are not well-defined and were not verified as recently active faults by this writer (figures 2a-2d). Locally, faults A and C have moderately defined features suggesting recent faulting, but an erosional origin for these features cannot be ruled out (localities 35, 36, figures 2a, 2b). Faults B and C are associated with closed basins (figure 2b). These playas could be related to recent faulting, but specific geomorphic features related to active faulting are lacking. It is possible that these closed basins are the result of broad, tectonic warping of the surface due to "micro-plate" interaction between the northwest-trending structures of the Mojave Block and the east-west-trending Pinto Mountain fault.

Moderately defined geomorphic features such as dissected scarps in late Pleistocene alluvium, ponded alluvium, deflected and constricted drainages, and tonal lineaments suggest latest Pleistocene oblique-slip displacement (up-to-east) along fault I (locality 37, figure 2d). The fault mapped by Bader and Moyle (1960) generally was not verified in detail by this writer, based on air photo interpretation (figure 2d).

SEISMICITY

Seismicity in the Yucca Valley - Twentynine Palms study area is depicted in figure 8. A and B quality epicenter locations by California Institute of Technology are for the period 1932 to 1985.

The Pinto Mountain fault zone is characterized by clusters of epicenters in the Yucca Valley area and near the junction with the Copper Mountain fault (figure 8). Although the Pinto Mountain fault may be seismically active at depth, it is not delineated by a well-defined zone of microseismicity.

The Mesquite Lake fault appears to be seismically quiescent, although a few scattered epicenters might be associated with the fault.

North of the Pinto Mountain fault zone, clusters of epicenters in the study area seem to be associated with the northwest-trending faults. The most obvious seismicity north of the study area is the Homestead Valley earthquake sequence, including a M5.2 event on March 15, 1979 (Hutton and others, 1980) (figure 8). Minor surface fault rupture along the Homestead Valley fault and the Johnson Valley fault was associated with this earthquake sequence (Hill and others, 1980). The southern part of the zone aftershocks is associated with fault I, the southern segment of the Johnson Valley fault zone (figure 8).

CONCLUSIONS

PINTO MOUNTAIN FAULT

The Pinto Mountain fault is a major, east-west-trending, left-lateral strike-slip fault that is transitional between the Mojave Desert and Transverse Ranges geomorphic provinces (figures 1, 2a-2d, 3a-3d). The Pinto Mountain fault zone generally is well defined in the study area and is characterized by geomorphic evidence of Holocene left-lateral strike-slip displacement (localities 3, 6, 7, 13, 22-25, figures 3a-3d). However, significant segments of the fault are concealed by alluvium of probable late Holocene age (e.g., localities 20, 21, figure 3b).

A site investigation by Rasmussen (1977) reported evidence of Holocene faulting along a well-defined segment of the Pinto Mountain fault mapped by this writer (locality 7, figures 3c, 4). Fault traces by Bader and Moyle (1960) and Bacheller (1978) were generally verified and faults mapped by Dibblee (1967, 1968a) were only locally verified by this writer (figures 2a-2d, 3a-3d). A site investigation by James (1986) reported evidence of Holocene displacement along a complex, left-stepping segment of the Pinto Mountain fault at locality 39 (figures 2a, 3a). Traces of the Pinto Mountain fault in the eastern part of the study area form a broad zone of moderately well-defined, discontinuous normal faults that offset late Pleistocene alluvium, but Holocene alluvium is not offset (Bacheller, 1978; figures 2a, 3a). This broad zone of faulting is probably the surface expression of a complex junction between the active, left-lateral Pinto Mountain fault and the active, right-lateral Mesquite Lake fault (figure 3a). At the western end of the study area, the Pinto Mountain fault zone is complex and generally not well defined except locally (figures 2d, 3d). The Pinto Mountain fault branches in the Yucca Valley area and recent activity may step left to a southern splay called the Morongo Valley fault (figure 2d). However, faults mapped by Bader and Moyle (1960), Dibblee (1967), and Grimes (1981) generally are not well defined in detail and generally could not be verified as Holocene active faults.

MESQUITE LAKE FAULT

The Mesquite Lake fault is a northwest-trending, right-lateral strike-slip fault (figures 2a, 3a). The Mesquite Lake fault is well defined and is characterized by geomorphic evidence of right-lateral strike-slip faulting (localities 29-32, figure 3a). A site investigation by Wahler Associates (1984) reported evidence of Holocene faulting along the Mesquite Lake fault. A carbonaceous silt bed offset along the fault was radiocarbon dated at 1200-1700 ybp (locality 16, figures 3a, 6). Faults mapped by Bader and Moyle (1960), Dibblee (1968a), Bacheller (1978), Morton and others (1980), and Wahler Associates (1984) were generally verified by this writer, although differences in detail exist (figures 2a, 3a). The western branch of the Mesquite Lake fault mapped by Bacheller (1978) is generally not well defined and geomorphic evidence of Holocene faulting is lacking (figures 2a, 3a).

The "Airfield fault" mapped by Fife (1978) and Wahler Associates (1984) is a north-trending, right-stepping set of fractures in Holocene alluvium that formed following an unusually intense rainfall in 1976 (Fife, 1978) (figure 2a). The fractures are extensional and trenching by Wahler Associates (1984) indicated that vertical or lateral offset of alluvium has not occurred along these fractures. The fractures are visible as tonal lineaments on 1978 BLM air photos, but could not be verified on 1952 USDA air photos. Fife (1978, 1980) and Wahler Associates (1984) concluded that the "Airfield fault" is probably a combination of left-lateral shear and extension in response to movement along the Mesquite Lake fault.

WEST BULLION MOUNTAIN

The West Bullion Mountain fault is a northwest-trending fault located east of the active Mesquite Lake fault (figure 2a). The West Bullion Mountain fault is not well defined and geomorphic evidence of Holocene faulting was not observed by this writer. Trenches excavated by Wahler Associates (1984) exposed evidence of minor late Pleistocene activity along the fault (figure 7), but a 35,000-50,000-year-old argillic B soil horizon overlying the fault was not offset (Foster, 1985).

COPPER MOUNTAIN FAULT

The Copper Mountain fault is a northwest-trending fault delineated by a well-defined, linear, southwest-facing escarpment in bedrock (figures 2b, 2c, 3b, 3c). The fault is generally well defined northwest of sec. 13, T1N, R7E and south of Sunfair Road and is delineated by subtle geomorphic evidence indicating Holocene down-to-the-west normal faulting (localities 19, 34, figure 3b). In addition, stream cut exposures revealed offset Holocene alluvium. Faults in the alluvial deposits varied in trend from N25^{o}W to N50^{o}W, and generally had southwest dips from 50^{o} to near vertical (figure 3b). Faults mapped by Bader and Moyle (1960), Dibblee (1967, 1968), and Morton and others (1980) were verified, in general, but significant differences in detail exist (figures 2b-2c, 3b-3c).

NORTHWEST-TRENDING FAULTS (FAULTS A-I)

Faults A-I are northwest-trending faults located north of the Pinto Mountain fault (figures 2a-2d). Fault traces mapped by Bader and Moyle (1960) and Dibblee (1967, 1968a) generally were not verified as Holocene active faults by this writer, based on air photo interpretation (figures 2a-2d). Locally, faults A, C, and F have moderately defined geomorphic features suggesting recent faulting, but the features are not continuous and an erosional origin cannot be ruled out (localities 35, 36, figures 2a, 2b). The trace of fault I (southern Johnson Valley fault) mapped by Bader and Moyle (1960) was not verified in detail by this writer (figure 2d). However, geomorphic features delineating fault I, as mapped by this writer, are permissive of latest Pleistocene and, possibly, Holocene displacement (locality 37, figure 2d). These moderately defined geomorphic features are associated with the southern extent of the aftershock zone of the March 15, 1979 Homestead Valley earthquake (Hutton and others, 1980). Minor surface fault rupture was reported along segments of the Johnson Valley fault zone just north of the FER study area (Hill and others, 1980; Manson, 1986).

The closed basins associated with faults B and C could be related to active faulting, but neither fault B nor C is well defined and is not characterized by additional geomorphic evidence of Holocene active faulting (figure 2b). The closed basins conceivably could be associated with active tectonic deformation caused by surface warping resulting from interaction along and near the east-trending Pinto Mountain fault zone. This interaction could partly explain the seismicity north of the Pinto Mountain fault between fault B and the Copper Mountain fault (figure 8).

RECOMMENDATIONS

Recommendations for zoning faults for special studies are based on the criteria of "sufficiently active" and "well-defined" (Hart, 1985).

PINTO MOUNTAIN FAULT

Zone for special studies well-defined faults shown on figures 9a-9d. Principal references cited should be Bacheller (1978), Dibblee (1967), and this FER.

MESQUITE LAKE FAULT

Zone for special studies well-defined faults shown on figure 9a. Principal references cited should be Bacheller (1978), Morton and others (1980), Wahler Associates (1984), and this FER. Zone for special studies traces of the "Airfield fault" mapped by Wahler Associates (1984).

WEST BULLION MOUNTAIN FAULT

Do not zone for special studies. This fault is neither sufficiently active nor well-defined.

COPPER MOUNTAIN FAULT

Zone for special studies well-defined faults shown on figures 9b and 9c. Principal references cited should be Morton and others (1980) and this FER.

NORTHWEST-TRENDING FAULTS A-I

Do not zone faults A-H for special studies. These faults are neither sufficiently active nor well-defined. Zone for special studies traces of fault I shown on figure 9d. Principal reference cited should be this FER.

Air Photos checked --
I concur with conclusions
and recommendations for
zoning Earl W. Hart
12/16/86

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December 2, 1986

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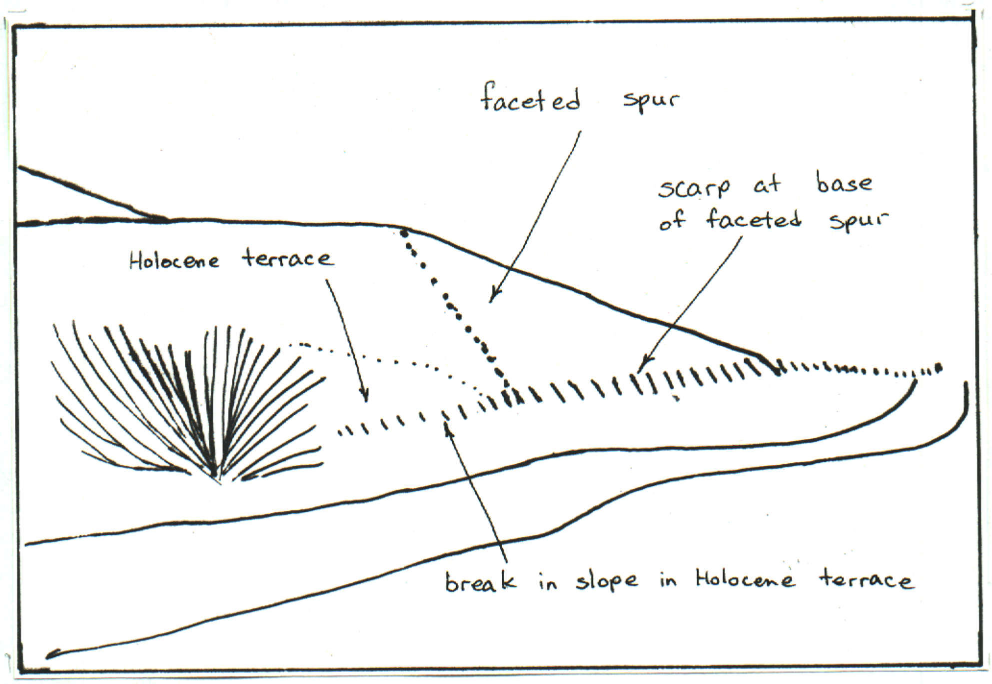
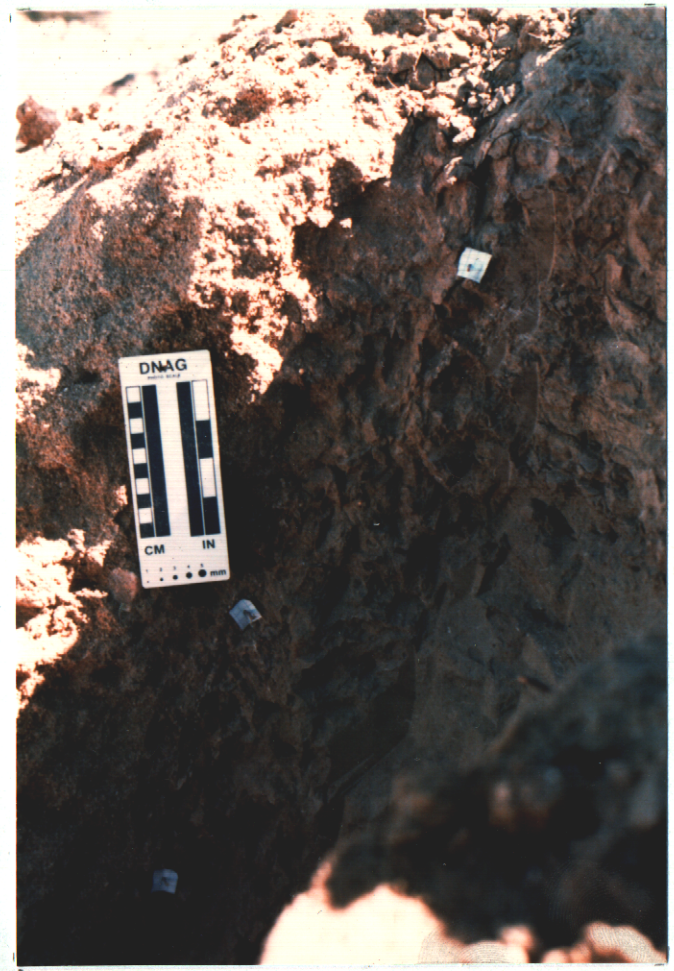


Photo 1 (to FER-181). View west along the Pinto Mountain fault near locality 23 (figure 3b). Evidence of multiple offsets along the fault is indicated by the compound scarp in moderately indurated mid-Pleistocene Campbell Hill Formation (lower scarp angle is approximately 35°). A down-to-the north break in slope in poorly indurated Holocene terrace deposits indicates Holocene activity along the Pinto Mountain fault.

2



3

Photos 2 and 3 (to FER-181). View east along the Pinto Mountain fault near locality 23 (figure 3b). Photo 2 shows compound north-facing scarp in Pleistocene Campbell Hill Formation. Photo 3 shows Pinto Mountain fault plane (white squares; E-W strike, 70°N dip). Fault juxtaposes med-coarse sand on the north (left) against fine silty sand and mudstone on the south (right). Bedding in fine sand dips about 25°SW. Weak striations on fault plane plunge 15°-20°W, indicating component of up-to-south vertical displacement along a left-lateral strike-slip fault.

A

B

Photo 4 (to FER-181). Stream-cut exposure of Copper Mountain fault; view to the northwest. A). Fault zone consists of two faults. Fault to east (right) of insert is in well-jointed granitic bedrock (N40° -55° W, near vertical dip) and doesn't seem to offset overlying alluvium. Western fault in alluvium is coincident with a 2 m high, southwest-facing scarp. B).. Fault indicated by vertically aligned clasts and juxtaposed poorly indurated alluvium on left against loose sand on right (sand-filled fissure?). Location of exposure is at locality 19, figure 3b.

Photo 5 (to FER-181). Stream-cut exposure of Copper Mountain fault; view to the southeast. Fault offsets a weak cambic (?) B soil horizon and overlying gravel deposits (note alignment of clasts in gravel deposit parallel to fault plane). Fault strikes N25 W and dips 75 SW. Location of exposure is just northwest of locality 19, figure 3b.

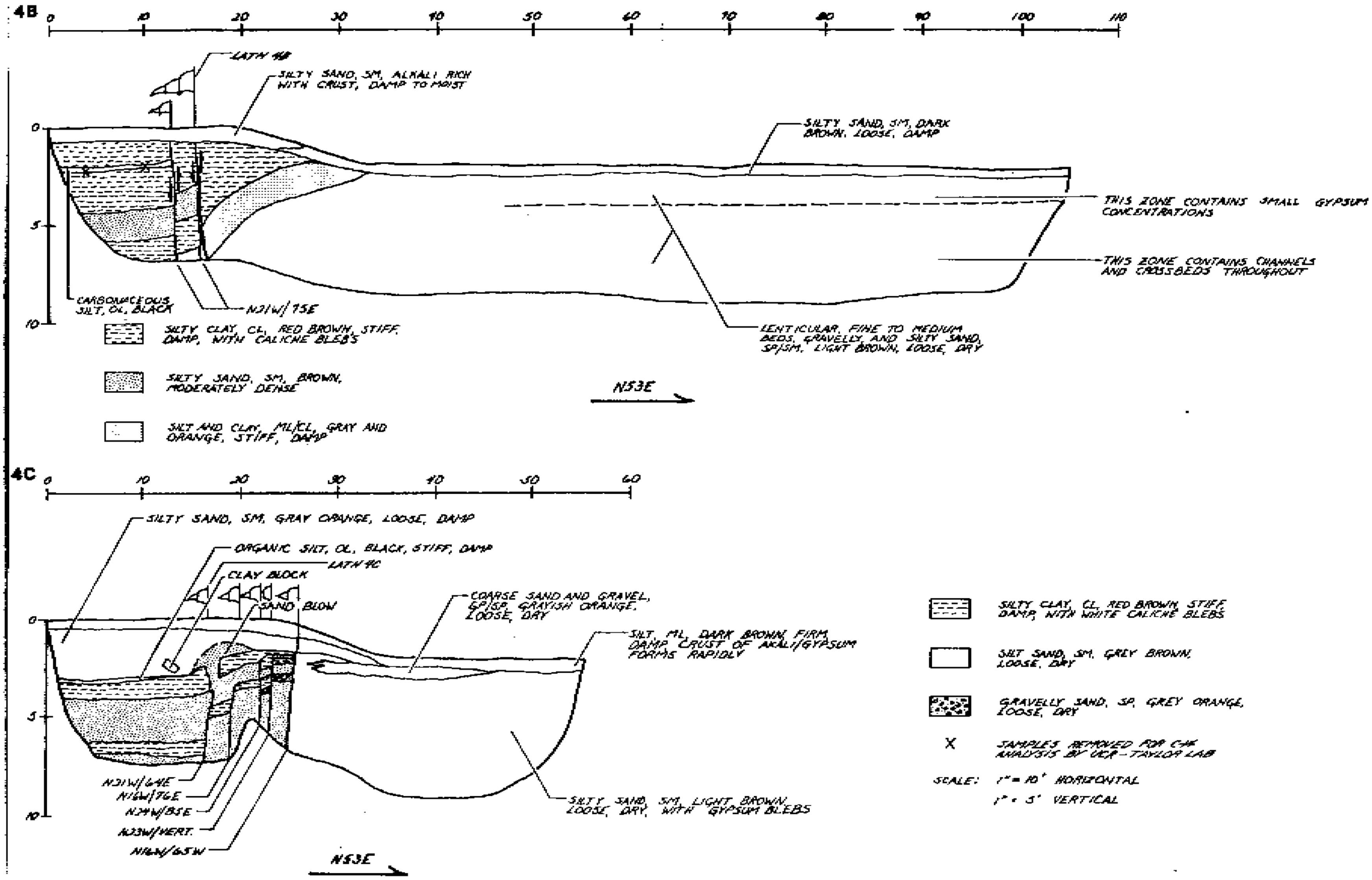


Figure 6 (to FER-181). Log of trench T-4B and T-4C excavated by Wahler Associates (1984) along the Mesquite Lake fault. Refer to locality 30, figures 2a and 3a for location of trenches.

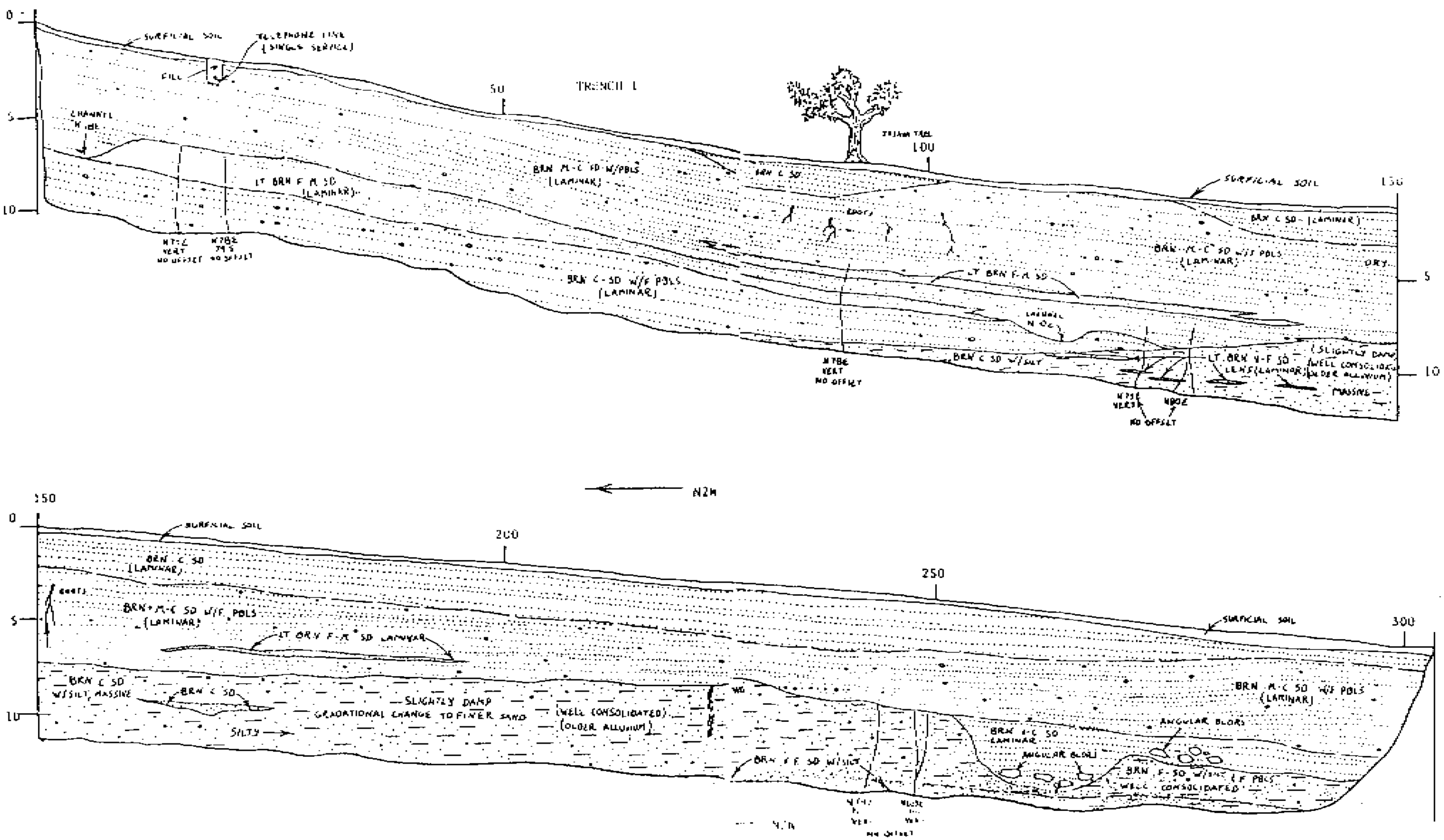


Figure 5 (to FER-181). Log of trench 1 excavated by Bush and Rasmussen (1979) along the Pinto Mountain fault. Refer to locality 13, figures 2d and 3d for location of trench.

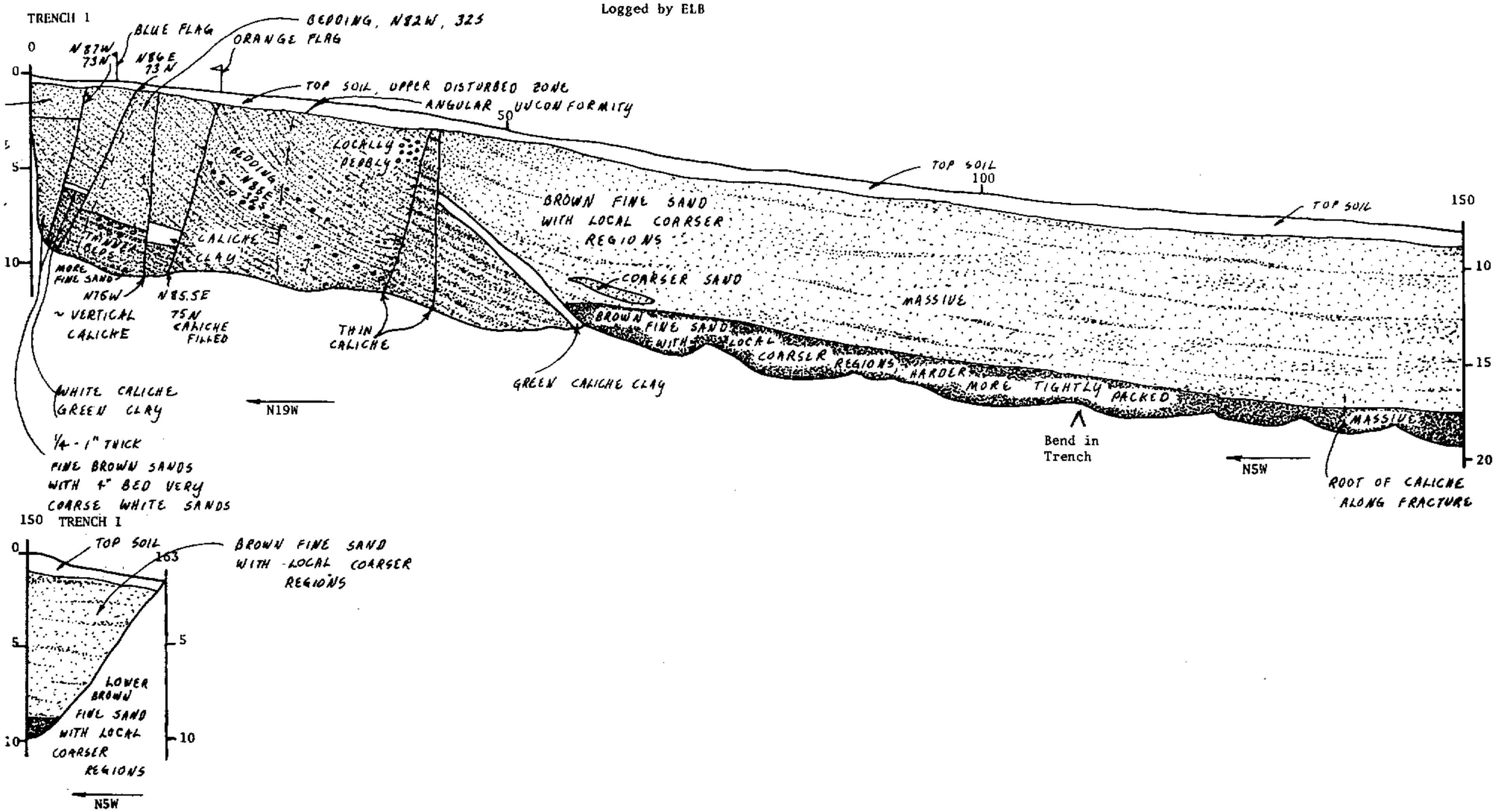


Figure 4 (to FER-181). Log of trench 1 excavated by Rasmussen (1977) along the Pinto Mountain fault. Refer to locality 7, figures 2c and 3c for location of trench.

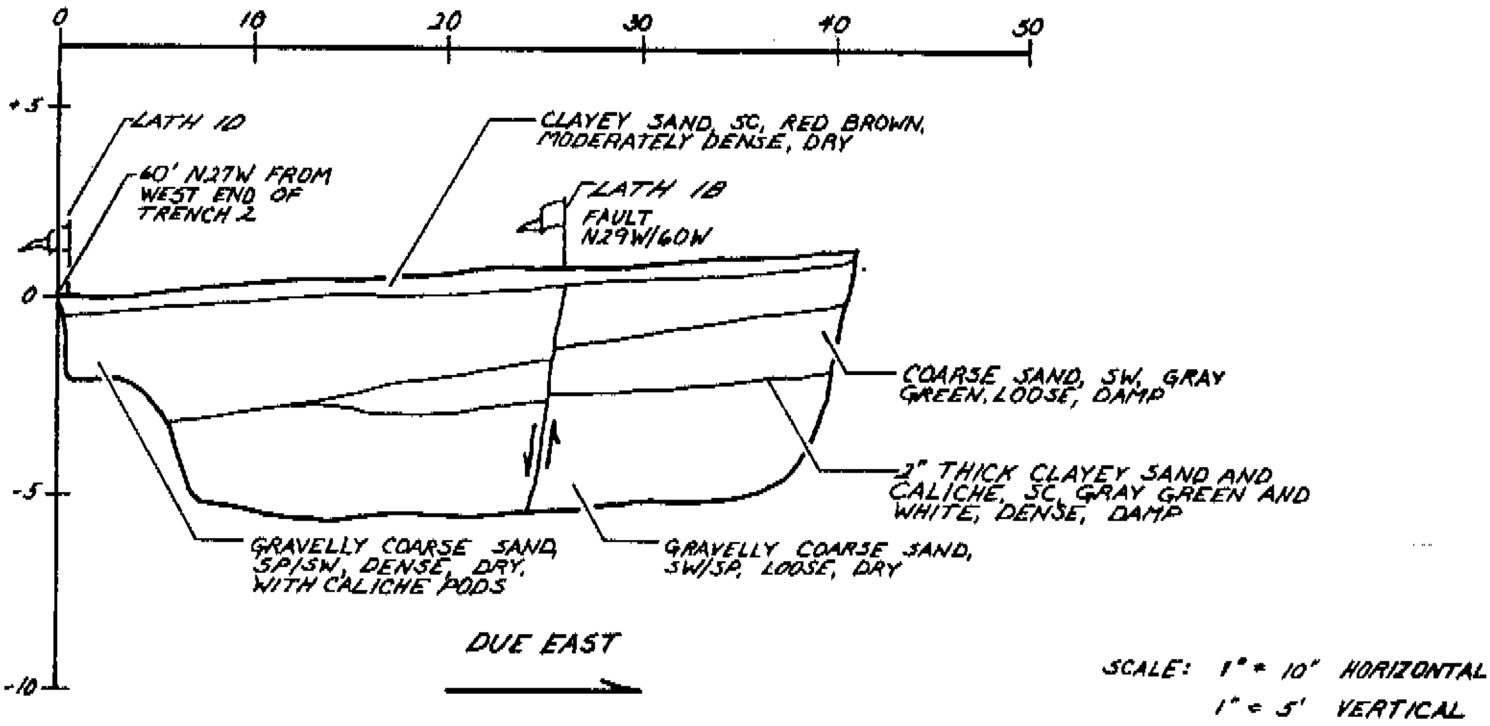


Figure 7 (to FER-181). Log of trench T-1C excavated by Wahler Associates (1984) along the West Bullion Mountain fault. Refer to figure 2a for location of trench.

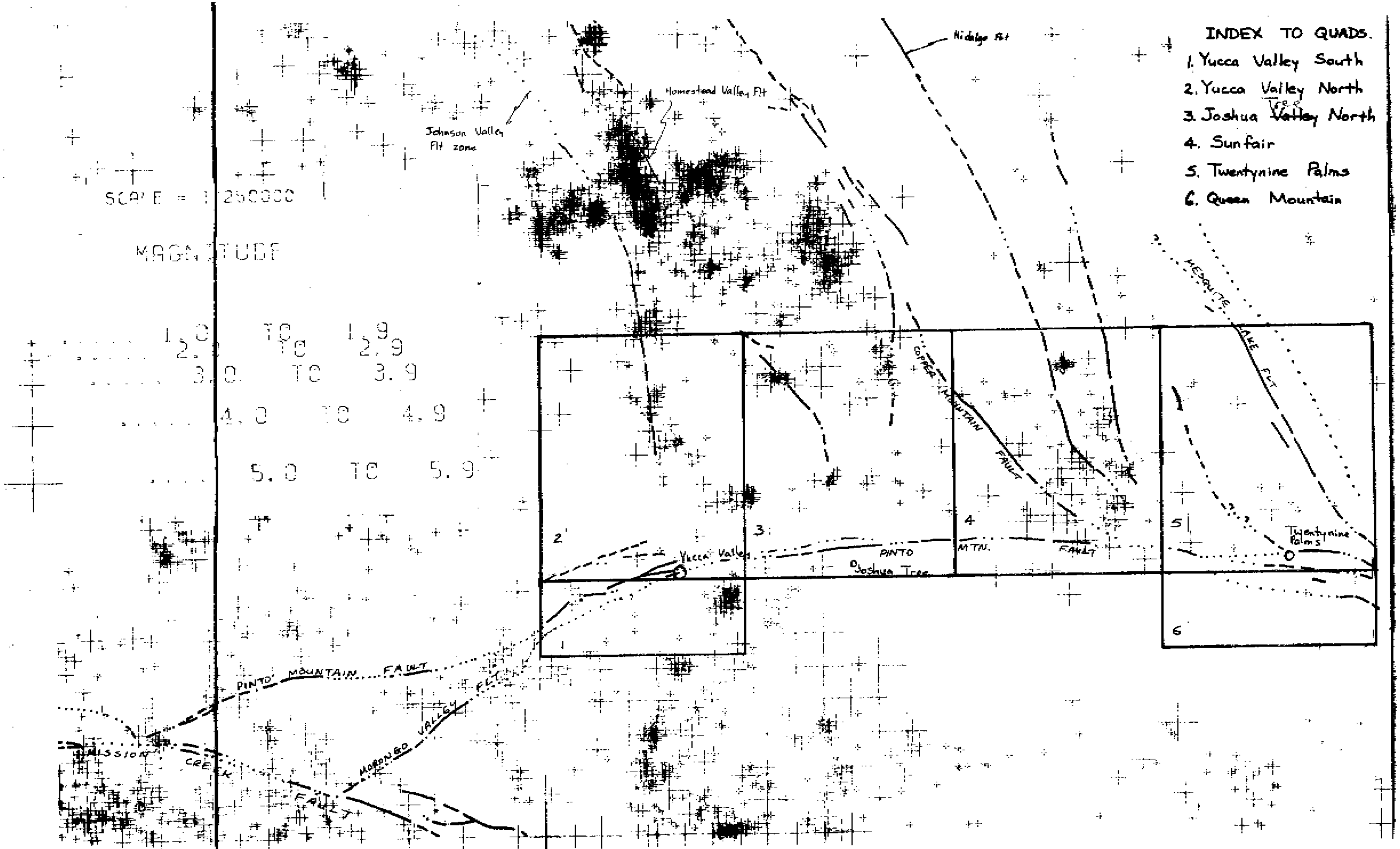


Figure 8 (to FER-181). Seismicity (A and B quality) in the Yucca Valley-Twentynine Palms area for the period 1932 to mid-1985, based on locations from California Institute of Technology (1985). Faults are from Rogers (1967) and Bortugno and Spittler (1986).